Searches for new physics using the $t\bar{t}$ invariant mass distribution in pp collisions at $\sqrt{s} = 8$ TeV

S. Chatrchyan *et al.**

(CMS Collaboration)

(Received 8 September 2013; published 22 November 2013)

Searches for anomalous top quark-antiquark production are presented, based on pp collisions at $\sqrt{s} = 8$ TeV. The data, corresponding to an integrated luminosity of 19.7 fb^{-1}, were collected with the CMS detector at the LHC. The observed $t\bar{t}$ invariant mass spectrum is found to be compatible with the standard model prediction. Limits on the production cross section times branching fraction probe, for the first time, a region of parameter space for certain models of new physics not yet constrained by precision measurements.

DOI: 10.1103/PhysRevLett.111.211804 PACS numbers: 12.60.−i, 13.85.Ni, 14.65.Ha

With the discovery of a Higgs boson with a mass around 125 GeV [1–3], the focus of particle physics has shifted towards understanding the properties of the new boson, uncovering the nature of the underlying electroweak symmetry breaking (EWSB) mechanism, and finding new physics. The standard model (SM) is believed to be an effective theory, i.e., a low-energy approximation of a more complete theory incorporating gravity and explaining the origin of many parameters that are simply postulated within the SM. Many models beyond the SM (BSM) have been proposed in order to alleviate the hierarchy problem of the SM, which stems from the fact that quantum-loop corrections to the Higgs boson mass diverge quadratically with the highest energy scale of the model, requiring an enormous degree of fine-tuning to ensure that the Higgs mass remains close to the W-boson mass up to the Planck scale. Since the largest quantum correction to the Higgs boson mass involves a top quark loop, it is natural to suppose that these BSM mechanisms would involve interactions with the top quark.

Potential solutions to the hierarchy problem include models with extra spatial dimensions, either flat [4] or warped [5,6]. In these models, gravity is allowed to permeate the multidimensional space, which results in its apparent weakness from the point of view of an observer restricted to 3 + 1 dimensions. This effect lowers the highest energy scale in the SM from the Planck scale to the TeV scale, thus eliminating the hierarchy between the EWSB scale and the highest scale in the theory. Such models often contain Kaluza-Klein excitations of particles, including gravitons and gluons, both of which can have enhanced couplings to $t\bar{t}$ pairs [7]. Other new gauge bosons have been proposed, referred to generically as Z', that also couple preferentially to $t\bar{t}$ pairs [8–13]. Furthermore, there may be additional spin-zero resonances that preferentially decay to $t\bar{t}$ pairs [13,14]. These various resonances may be observable as enhancements in the $t\bar{t}$ invariant mass spectrum.

Discrepancies have been observed in the forward-backward asymmetry of top quark production at the Tevatron [15]. Assuming this anomaly is due to new physics above the TeV scale, an enhancement of the $t\bar{t}$ rate at high invariant mass could be visible at the Large Hadron Collider (LHC) [16,17].

In this Letter, a search for anomalous production of $t\bar{t}$ events is presented, from data corresponding to an integrated luminosity of 19.7 fb^{-1} of pp collisions at $\sqrt{s} =$ 8 TeV, recorded with the Compact Muon Solenoid (CMS) detector [18] at the LHC. These results represent a significant improvement over the previous searches [19–24], due primarily to the large increase in the high-x parton luminosity from the higher LHC energy in 2012, but also because of the increased size of the data sample and the combination of several statistically independent channels. Specific comparisons are made to the resonant production of Randall-Sundrum Kaluza-Klein (RS KK) gluons [7], of a Z' boson in the topcolor model [10], and of a scalar Higgs-like boson produced via gluon fusion through its couplings to the top quarks. In addition, enhancements of the $t\bar{t}$ invariant mass ($M_{t\bar{t}}$) spectrum are constrained for $M_{t\bar{t}} >$ 1 TeV. These results probe, for the first time, a region of parameter space of models with warped extra dimensions not yet constrained by precision measurements [25].

Since the top quark decays primarily to a W boson and a bottom (b) quark, top pair production signatures are classified based on whether the W bosons decay to leptons or quarks. This measurement combines analyses utilizing the final states where one or both W bosons from $t\bar{t}$ events decay to quarks (“semileptonic” and “all-hadronic” events, respectively). The events are classified into two categories based on the expected kinematics of the top quark decay products. In the first category, the $t\bar{t}$ pair is produced near the kinematic threshold, resulting in a topology where each parton is matched to a single jet

*Full author list given at the end of the article.

("resolved topology"). In the second category, each top quark is produced with a high Lorentz boost (>2), resulting in collimated decay products that may be clustered into a single jet ("boosted topology"). The transition between the resolved and boosted topologies occurs around $M_{t\bar{t}} =$ 1 TeV. Both the resolved and boosted topologies are used to analyze the semileptonic events. However, all-hadronic events are analyzed only in the boosted topology, which is combined with the semileptonic boosted events to perform the search. As the all-hadronic analysis is dominated by multijet events, jet substructure criteria are imposed to further enhance sensitivity. The analysis techniques are similar to those explored in earlier analyses of pp collision data [20,23].

The CMS detector, a general-purpose apparatus operating at the CERN LHC, is described in detail elsewhere [18]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel magnetic flux return yoke outside the solenoid.

At the CMS experiment, the polar angle θ is measured from the beam direction and the azimuthal angle ϕ is measured perpendicular to the beam direction. The rapidity y is approximated by the pseudorapidity η, defined as $\eta = -\ln[\tan(\theta/2)]$. The transverse momentum perpendicular to the beam line is denoted as p_{T}.

The CMS experiment uses a particle-flow-based event reconstruction [26], which aggregates information from all subdetectors, including charged-particle tracks from the tracking system and deposited energy from the electromagnetic and hadron calorimeters. Given this information, all detected particles in the event are reconstructed as electrons, muons, photons, neutral hadrons, or charged hadrons. For this paper, electrons and photons are required to have $|\eta| < 2.5$, and muons, $|\eta| < 2.1$. The leading hard-scattering vertex of the event is defined as the vertex whose tracks have the largest squared-sum of transverse momentum. Charged hadrons associated with other vertices are removed from further consideration. The remaining candidates are clustered into jets using the FASTJET 3.0 software package [27]. The semileptonic analyses use the anti-k_{T} jet-clustering algorithm [28] with a size parameter of 0.5 (AK5 jets), while the all-hadronic analysis uses the Cambridge-Aachen (CA) jet-clustering algorithm [29,30] with a size parameter of 0.8 (CA8 jets) to take advantage of the capability of the CA algorithm to distinguish jet substructure. Jets are required to satisfy $|\eta| < 2.4$. Jets are identified as b-quark jets if they satisfy the combined secondary vertex algorithm defined in Ref. [31].

The data for the semileptonic resolved category were collected with triggers requiring a single isolated muon or electron with a p_{T} threshold of 17 or 25 GeV, respectively, in combination with three jets with $p_{\mathrm{T}} > 30$ GeV. Offline, we select events containing exactly one isolated muon (with $p_{\mathrm{T}}^{\mu} > 26$ GeV), or electron (with $p_{\mathrm{T}}^{e} > 30$ GeV), and at least four jets with $p_{\mathrm{T}} > 70, 50, 30, 30$ GeV, respectively. The non-W multijet background (NWMJ) is suppressed further by requiring the transverse missing momentum $E_{\mathrm{T}}^{\mathrm{miss}}$, the modulus of the vector sum of all measured particle p_{T}, to be larger than 20 GeV.

For the semileptonic boosted category, data were recorded with triggers requiring one muon ($p_{\mathrm{T}}^{\mu} >$ 40 GeV), or one electron ($p_{\mathrm{T}}^{e} > 35$ GeV) in conjunction with two jets ($p_{\mathrm{T}} > 100$, 25 GeV). Since the top quark decay products can be collinear in this regime, no isolation requirements on the leptons are imposed in either the trigger or offline selections. Offline, we select events containing exactly one muon with $p_{\mathrm{T}}^{\mu} > 45$ GeV, or exactly one electron with $p_{\mathrm{T}}^{e} > 35$ GeV and at least two jets with $p_{\mathrm{T}} > 150$, 50 GeV, respectively. To reduce the contamination of the NWMJ processes, we follow the techniques of Ref. [23], placing requirements on the angle and relative momentum between the lepton and the nearest jet, and also requiring $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{e,\mu} > 150$ GeV.

The events satisfying the two semileptonic selections are separated into categories determined by the lepton flavor (electron or muon) and the number of b-tagged jets $N_{b\text{-tag}}$ (1 or ≥ 2 b-tagged jets for the resolved analysis, and 0 or ≥ 1 b-tagged jets for the boosted analysis). The purpose of this classification is to separate the sample into regions dominated by different background processes. The events in the categories with fewer b-tagged jets have a higher fraction of $W+$jets events, whereas those with more b-tagged jets have a higher fraction of $t\bar{t}$ events. This characterization is used to constrain the various background components by imposing self-consistency among the channels. The reconstruction of semileptonic $t\bar{t}$ candidates relies on a χ^2 variable built by enforcing kinematic consistency (within uncertainties) with the $t\bar{t}$ hypothesis, imposing constraints on the reconstructed W and top candidates. In the semileptonic boosted regime we follow the techniques of Ref. [23], and allow candidates with more than one parton merged into a single jet.

For the boosted all-hadronic analysis, data were recorded with a trigger requiring the scalar sum of the transverse momenta of reconstructed AK5 jets to be greater than 750 GeV. In the offline analysis selection, we require two CA8 jets, each with $p_{\mathrm{T}} > 400$ GeV.

The reconstruction of the boosted all-hadronic analysis relies on "top-tagging" techniques similar to those used in the previous analysis [20]. This algorithm [32], aiming to identify the top quark decay products within CA8 jets, reverses the jet-clustering sequence by iteratively separating the jet into subjets until three or four subjets with sufficient p_{T} are found. The algorithm is validated on a sample of $t\bar{t}$ events selected by requiring one muon and additional jets [33]. The reconstructed single jet top quark mass is found to be consistent with the expectation from simulated events, as is the disubjet W mass, obtained from the minimum mass pairing of the leading three subjets. The two selected top-tagged jets are then required to be back to back, with $|\Delta\phi| > \pi/2$ and $|\Delta y| < 1.0$, to suppress nontop multijet (NTMJ) backgrounds.

SM top quark production is modeled with the next-to-leading-order (NLO) generator POWHEG (v1.0) [34], interfaced with PYTHIA 6 (v6.2.24) [35] for parton showering with tune $Z2^*$ [36]. MADGRAPH (v5.1.1) [37] interfaced to PYTHIA 6 is used for simulating W and Z boson production in association with jets. Diboson processes are generated with PYTHIA 6 to compute both the matrix element and showering.

The MADGRAPH -PYTHIA 6 combination is also used to generate signal Monte Carlo (MC) simulation events for limit setting, including high-mass SM-like Z' resonances with $\Gamma_{Z'}/M_{Z'} = 1\%$ and $\Gamma_{Z'}/M_{Z'} = 10\%$, where $\Gamma_{Z'}$ is the width of the resonance, and $M_{Z'}$ is the mass. This relative width can be compared to the detector resolution of about 10% for a $t\bar{t}$ resonance mass. Hence, limits set for the Z' with a width of 1% would apply to a larger class of models in which the resonance width is below the experimental resolution. The MADGRAPH -PYTHIA 6 combination is also used to generate a simplified model of a spin-zero resonance produced via gluon fusion through its couplings to top quarks, with the SM interference effects neglected in the model. A Kaluza-Klein excitation of a gluon with a width of approximately 15%–20% [7] is generated with PYTHIA 8 (v1.5.3) [38].

The leading-order (LO) CTEQ6L parton distribution functions [39] are used, except for the generation of the POWHEG samples, which use the NLO CT10 parton distribution function [40]. All MC samples include additional collisions per beam crossing and are reweighted to match the data taking conditions as well as the identification and trigger efficiencies measured in control samples.

For the semileptonic resolved analysis, an aggregate background estimate is taken for all SM components together directly from the data, with the SM $t\bar{t}$ component the dominant one. The number of signal events is extracted from a binned maximum likelihood fit to the $M_{t\bar{t}}$ distribution, assuming a smoothly falling probability density function (pdf) for the SM backgrounds and a parametrization of the signal pdf based on a Breit-Wigner shape. Only events with $M_{t\bar{t}} > 550$ GeV are considered; below this value the SM backgrounds are not described by a smoothly falling pdf.

The $M_{t\bar{t}}$ distributions of the semileptonic and all-hadronic boosted topologies are fitted together in a single joint likelihood maximization, imposing consistency of the various background and signal components across the two channels. The initial estimates for the SM $t\bar{t}$, single-top quark, W + jets, and diboson production are based on simulation after applying data-MC corrections based on control samples in data. The boosted all-hadronic analysis has one additional background component, the NTMJ background, which is estimated using the probability to misidentify a light-parton jet as a top quark jet measured in data. This probability is derived as a function of the jet p_T in a sample enriched in light-quark jets, kinematically

TABLE I. Constraints used in the likelihood maximization. The $M_{t\bar{t}}$ distributions of the boosted channels are combined into a single joint likelihood, imposing consistency of the various background and signal components.

	Resolved semileptonic	Boosted semileptonic	Boosted all-hadronic
Constraints on normalization			
Luminosity [41]	2.6%	2.6%	2.6%
Pileup	6%	6%	6%
$t\bar{t}$ [42]	···	15%	15%
Parton distribution functions [43]	1σ	1σ	1σ
Single top	···	50%	···
W +light-flavor jets	···	50%	···
W +heavy-flavor jets	···	100%	···
Z + jets	···	100%	···
Lepton selection	0.5–3.0%	0.5–3.0%	···
Top-tagging efficiency	···	···	9%
Constraints on shape			
$t\bar{t}$ renormalization, factorization, and matching scales	···	variation by $\times 2$ and $\times 0.5$	
Jet energy scale	1–6%	1–6%	1–6%
Jet energy resolution	8–10%	8–10%	8–10%
b-tagging efficiency	2–8%	2–8%	···
b-tagging mis-ID	···	20%	···
Top-tagging mis-ID	···	···	5–20%
Signal and background pdf	1σ	···	···

TABLE II. Number of expected and observed events in the boosted analyses.

Sample	Semileptonic $N_{b\text{-tag}} = 0$	Semileptonic $N_{b\text{-tag}} \geq 1$	All-hadronic $M_{t\bar{t}} \geq 1$ TeV
$t\bar{t}$	5440 ± 520	9090 ± 870	510 ± 90
NTMJ	$\cdots$	$\cdots$	6600 ± 200
Others	5880 ± 820	1070 ± 380	$\cdots$
Total SM	11320 ± 1300	10160 ± 1300	7110 ± 410
Data	10305	10159	6887

similar to the signal region. It is then used to weight events in the signal region. Furthermore, the efficiency for identifying true top quark jets is corrected in the signal MC simulations using measurements in a signal-depleted sideband region containing events with one isolated muon and additional jets. It is found that the efficiencies in data and MC simulations agree, having a ratio of $93 \pm 5\%$. The methods described above were validated using simulated samples and it was verified that signal contamination was minimal in the signal-depleted regions.

In the likelihood maximization, systematic uncertainties are treated as nuisance parameters. Those that are common among the channels are treated as 100% correlated, while those that are channel-specific are treated as uncorrelated.

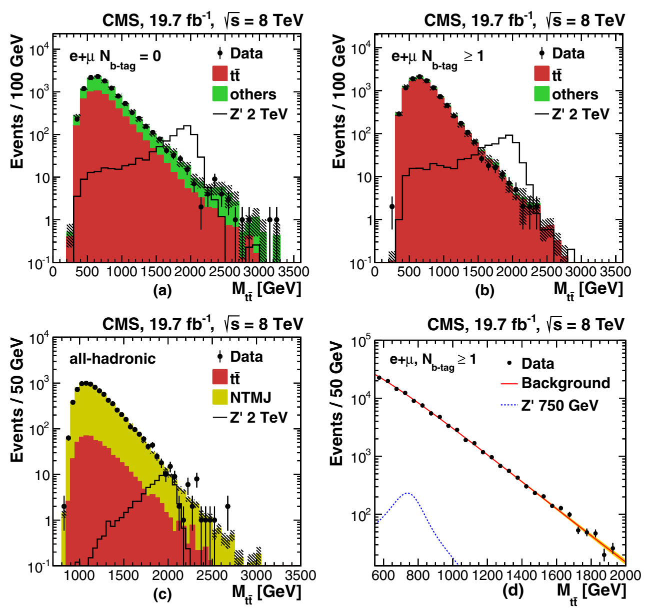

FIG. 1 (color online). Comparison between data and SM prediction for reconstructed $M_{t\bar{t}}$ distributions for the boosted semileptonic analysis with 0 b-tagged jets (a) and ≥ 1 b-tagged jets (b), as well as for the all-hadronic analysis (c). For the semileptonic analyses, "others" refers to all nontop backgrounds, while for the all-hadronic analysis, "NTMJ" refers to the "nontop multijet" background. The shaded band corresponds to the SM background uncertainty. The likelihood fit projection on data for the semileptonic resolved analysis is shown in (d). A cross section of 1.0 pb is used for the normalization of the Z' samples.

The normalizations of the backgrounds are allowed to vary within log-normal constraints in the maximization of the joint likelihood. The shapes of the backgrounds are also allowed to vary within their uncertainties. The shapes and normalizations also account for systematic variations due to efficiency and misidentification rates. The constraints used in the joint likelihood maximization are listed in Table I.

The event yields from the various background components and data are shown in Table II. The yields of the simulated samples are quoted after the likelihood maximization procedure, and the individual background uncertainties include only the uncertainty in the individual normalization. The total SM contribution includes all uncertainties, including the correlations not quoted in the individual components. Figure 1 shows the $M_{t\bar{t}}$ distributions for all channels along with the expectation from a Z' signal.

In all cases, the data are well described by the SM-only background hypothesis. The absence of a signal in the $M_{t\bar{t}}$ distribution is quantified by deriving Bayesian upper limits on the signal cross section times branching fraction at 95% confidence level (C.L.), using pseudoexperiments. The resolved semileptonic analysis has some overlapping phase space with the boosted semileptonic analysis, and there is a transition point (~ 1 TeV) where the expected sensitivities of the boosted and resolved analyses are equal, above which the boosted analysis result is quoted, and below which the resolved analysis result is quoted.

Figure 2 shows the expected and observed limits for a narrow resonance, as a function of the invariant mass of the resonance. The specific example shown in Fig. 2 and given by the dashed line refers to a topcolor Z' with $\Gamma_{Z'}/M_{Z'} = 1.2\%$ based on predictions from Ref. [10]. The cross section limits for this case are obtained from the MC models with $\Gamma_{Z'}/M_{Z'} = 1.0\%$, scaled by the ratio of theoretical

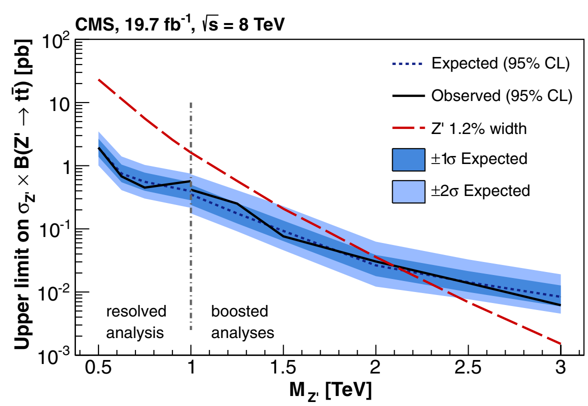

FIG. 2 (color online). The 95% C.L. upper limits on the production cross section times branching fraction as a function of $M_{t\bar{t}}$ for Z' resonances with $\Gamma_{Z'}/M_{Z'} = 1.2\%$ compared to predictions from Ref. [10] multiplied by 1.3 to account for higher-order effects [44].

TABLE III. 95% C.L. lower limits on the masses of new particles in specific models.

Model	Observed limit	Expected limit
Z', $\Gamma_{Z'}/M_{Z'} = 1.2\%$	2.1 TeV	2.1 TeV
Z', $\Gamma_{Z'}/M_{Z'} = 10\%$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

cross sections. This scaling is done to compare to theoretical results and previous measurements. As the cross section calculation is available for this model at LO only, the predictions are multiplied by a factor of 1.3 to account for higher-order effects [44]. The vertical dash-dotted line indicates the transition between the resolved and boosted analyses. Table III shows additional model-specific limits. The combination of the semileptonic and all-hadronic boosted analyses improves the expected cross section limits at 2 TeV by $\sim$25%. Compared to the results of previous analyses [20–23] for specific models [7,10], the lower limits on the masses of these resonances have been improved by several hundred GeV. For the semileptonic resolved analysis, assuming a spin-zero resonance with narrow width, produced via gluon fusion with no interference with the SM background, the cross section limits are 0.8 pb and 0.3 pb for a spin-zero resonance of mass 500 and 750 GeV, respectively. These are the first limits at CMS for heavy Higgs-like particles decaying into $t\bar{t}$.

In addition to investigating possible resonant structures in the $M_{t\bar{t}}$ spectrum, the presence of new physics that causes a nonresonant enhancement of the $M_{t\bar{t}}$ spectrum is also tested. The boosted all-hadronic analysis is used to set limits on such new production for events with $M_{t\bar{t}} >$ 1 TeV, since the NTMJ background can be predicted entirely from data. The limit is expressed as a ratio of the total SM + BSM $t\bar{t}$ cross section to the SM-only cross section ($\mathcal{S}$, as defined in Ref. [20]). The efficiency to select SM $t\bar{t}$ events with $M_{t\bar{t}} > 1$ TeV is $(3.4 \pm 1.7) \times 10^{-4}$. We find $\mathcal{S} < 1.2$ at the 95% C.L., with a credible interval of 1.1–2.0 at 68% C.L., a factor of 2 improvement over the previously published limits [20].

In summary, we have performed searches for anomalous $t\bar{t}$ production using events in the semileptonic and all-hadronic topologies. In addition to new limits on nonresonant enhancements to top quark production, limits are set on the production cross section times branching fraction for several resonance hypotheses, for resonances in the mass range 0.5–3.0 TeV.

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

[1] ATLAS Collaboration, Phys. Lett. B **716**, 1 (2012).
[2] CMS Collaboration, Phys. Lett. B **716**, 30 (2012).
[3] CMS Collaboration, J. High Energy Phys. 06 (2013) 081.
[4] N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali, Phys. Lett. B **429**, 263 (1998).
[5] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999).
[6] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 4690 (1999).
[7] K. Agashe, A. Belyaev, T. Krupovnickas, G. Perez, and J. Virzi, Phys. Rev. D **77**, 015003 (2008).
[8] N. Arkani-Hamed, A. G. Cohen, and H. Georgi, Phys. Lett. B **513**, 232 (2001).
[9] J. L. Rosner, Phys. Lett. B **387**, 113 (1996).
[10] R. M. Harris and S. Jain, Eur. Phys. J. C **72**, 2072 (2012).
[11] P. H. Frampton and S. L. Glashow, Phys. Lett. B **190**, 157 (1987).
[12] D. Choudhury, R. M. Godbole, R. K. Singh, and K. Wagh, Phys. Lett. B **657**, 69 (2007).
[13] D. Dicus, A. Stange, and S. Willenbrock, Phys. Lett. B **333**, 126 (1994).
[14] R. Frederix and F. Maltoni, J. High Energy Phys. 01 (2009) 047.
[15] K. Lannon, F. Margaroli, and C. Neu, Eur. Phys. J. C **72**, 2120 (2012).
[16] J. A. Aguilar-Saavedra and M. Perez-Victoria, J. High Energy Phys. 05 (2011) 034.
[17] C. Delaunay, O. Gedalia, Y. Hochberg, G. Perez, and Y. Soreq, J. High Energy Phys. 08 (2011) 031.
[18] CMS Collaboration, JINST **3**, S08004 (2008).
[19] F. Déliot, Y. Peters, and V. Sorin (CDF/D0), Int. J. Mod. Phys. A **28**, 1330013 (2013).
[20] CMS Collaboration, J. High Energy Phys. 09 (2012) 029.

[21] ATLAS Collaboration, Phys. Rev. D **88**, 012004 (2013).
[22] ATLAS Collaboration, J. High Energy Phys. 09 (2012) 041.
[23] CMS Collaboration, J. High Energy Phys. 12 (2012) 015.
[24] CMS Collaboration, Phys. Rev. D **87**, 072002 (2013).
[25] H. Davoudiasl, S. Gopalakrishna, E. Ponton, and J. Santiago, New J. Phys. **12**, 075011 (2010).
[26] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-PFT-09-001, 2009 [http://cds.cern.ch/record/1194487].
[27] M. Cacciari, G. P. Salam, and G. Soyez, Eur. Phys. J. C **72**, 1896 (2012).
[28] M. Cacciari, G. P. Salam, and G. Soyez, J. High Energy Phys. 04 (2008) 063.
[29] Y. L. Dokshitzer, G. D. Leder, S. Moretti, and B. R. Webber, J. High Energy Phys. 08 (1997) 001.
[30] M. Wobisch and T. Wengler, arXiv:hep-ph/9907280.
[31] CMS Collaboration, JINST **8**, P04013 (2013).
[32] D. E. Kaplan, K. Rehermann, M. D. Schwartz, and B. Tweedie, Phys. Rev. Lett. **101**, 142001 (2008).
[33] See Supplemental Material at http://link.aps.org/supplemental/10.1103/PhysRevLett.111.211804 for additional validation plots.
[34] S. Alioli, P. Nason, C. Oleari, and E. Re, J. High Energy Phys. 06 (2010) 043.
[35] T. Sjöstrand, S. Mrenna, and P. Z. Skands, J. High Energy Phys. 05 (2006) 026.
[36] CMS Collaboration, J. High Energy Phys. 09 (2011) 109.
[37] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, J. High Energy Phys. 06 (2011) 128.
[38] T. Sjöstrand, S. Mrenna, and P. Z. Skands, Comput. Phys. Commun. **178**, 852 (2008).
[39] P. M. Nadolsky, H.-L. Lai, Q.-H. Cao, J. Huston, J. Pumplin, D. Stump, W.-K. Tung, and C.-P. Yuan, Phys. Rev. D **78**, 013004 (2008).
[40] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, Phys. Rev. D **82**, 074024 (2010).
[41] CMS Collaboration, CMS Physics Analysis Summary Report No. CMS-PAS-LUM-13-001, 2013 [http://cds.cern.ch/record/1598864].
[42] CMS Collaboration, Phys. Rev. D **84**, 092004 (2011).
[43] J. Pumplin, D. Stump, R. Brock, D. Casey, J. Huston, J. Kalk, H. L. Lai, and W. K. Tung, Phys. Rev. D **65**, 014013 (2001).
[44] J. Gao, C. S. Li, B. H. Li, H. X. Zhu, and C.-P. Yuan, Phys. Rev. D **82**, 014020 (2010).

S. Chatrchyan,[1] V. Khachatryan,[1] A. M. Sirunyan,[1] A. Tumasyan,[1] W. Adam,[2] T. Bergauer,[2] M. Dragicevic,[2] J. Erö,[2] C. Fabjan,[2,b] M. Friedl,[2] R. Frühwirth,[2,b] V. M. Ghete,[2] N. Hörmann,[2] J. Hrubec,[2] M. Jeitler,[2,b] W. Kiesenhofer,[2] V. Knünz,[2] M. Krammer,[2,b] I. Krätschmer,[2] D. Liko,[2] I. Mikulec,[2] D. Rabady,[2,c] B. Rahbaran,[2] C. Rohringer,[2] H. Rohringer,[2] R. Schöfbeck,[2] J. Strauss,[2] A. Taurok,[2] W. Treberer-Treberspurg,[2] W. Waltenberger,[2] C.-E. Wulz,[2,b] V. Mossolov,[3] N. Shumeiko,[3] J. Suarez Gonzalez,[3] S. Alderweireldt,[4] M. Bansal,[4] S. Bansal,[4] T. Cornelis,[4] E. A. De Wolf,[4] X. Janssen,[4] A. Knutsson,[4] S. Luyckx,[4] L. Mucibello,[4] S. Ochesanu,[4] B. Roland,[4] R. Rougny,[4] Z. Staykova,[4] H. Van Haevermaet,[4] P. Van Mechelen,[4] N. Van Remortel,[4] A. Van Spilbeeck,[4] F. Blekman,[5] S. Blyweert,[5] J. D'Hondt,[5] A. Kalogeropoulos,[5] J. Keaveney,[5] M. Maes,[5] A. Olbrechts,[5] S. Tavernier,[5] W. Van Doninck,[5] P. Van Mulders,[5] G. P. Van Onsem,[5] I. Villella,[5] C. Caillol,[6] B. Clerbaux,[6] G. De Lentdecker,[6] L. Favart,[6] A. P. R. Gay,[6] T. Hreus,[6] A. Léonard,[6] P. E. Marage,[6] A. Mohammadi,[6] L. Perniè,[6] T. Reis,[6] T. Seva,[6] L. Thomas,[6] C. Vander Velde,[6] P. Vanlaer,[6] J. Wang,[6] V. Adler,[7] K. Beernaert,[7] L. Benucci,[7] A. Cimmino,[7] S. Costantini,[7] S. Dildick,[7] G. Garcia,[7] B. Klein,[7] J. Lellouch,[7] A. Marinov,[7] J. Mccartin,[7] A. A. Ocampo Rios,[7] D. Ryckbosch,[7] M. Sigamani,[7] N. Strobbe,[7] F. Thyssen,[7] M. Tytgat,[7] S. Walsh,[7] E. Yazgan,[7] N. Zaganidis,[7] S. Basegmez,[8] C. Beluffi,[8,d] G. Bruno,[8] R. Castello,[8] A. Caudron,[8] L. Ceard,[8] G. G. Da Silveira,[8] C. Delaere,[8] T. du Pree,[8] D. Favart,[8] L. Forthomme,[8] A. Giammanco,[8,e] J. Hollar,[8] P. Jez,[8] V. Lemaitre,[8] J. Liao,[8] O. Militaru,[8] C. Nuttens,[8] D. Pagano,[8] A. Pin,[8] K. Piotrzkowski,[8] A. Popov,[8,f] M. Selvaggi,[8] M. Vidal Marono,[8] J. M. Vizan Garcia,[8] N. Beliy,[9] T. Caebergs,[9] E. Daubie,[9] G. H. Hammad,[9] G. A. Alves,[10] M. Correa Martins Junior,[10] T. Martins,[10] M. E. Pol,[10] M. H. G. Souza,[10] W. L. Aldá Júnior,[11] W. Carvalho,[11] J. Chinellato,[11,g] A. Custódio,[11] E. M. Da Costa,[11] D. De Jesus Damiao,[11] C. De Oliveira Martins,[11] S. Fonseca De Souza,[11] H. Malbouisson,[11] M. Malek,[11] D. Matos Figueiredo,[11] L. Mundim,[11] H. Nogima,[11] W. L. Prado Da Silva,[11] A. Santoro,[11] A. Sznajder,[11] E. J. Tonelli Manganote,[11,g] A. Vilela Pereira,[11] C. A. Bernardes,[12b] F. A. Dias,[12a,h] T. R. Fernandez Perez Tomei,[12a] E. M. Gregores,[12b] C. Lagana,[12a] P. G. Mercadante,[12b] S. F. Novaes,[12a] Sandra S. Padula,[12a] V. Genchev,[13,c] P. Iaydjiev,[13,c] S. Piperov,[13] M. Rodozov,[13] G. Sultanov,[13] M. Vutova,[13] A. Dimitrov,[14] R. Hadjiiska,[14] V. Kozhuharov,[14] L. Litov,[14] B. Pavlov,[14] P. Petkov,[14] J. G. Bian,[15] G. M. Chen,[15] H. S. Chen,[15] C. H. Jiang,[15] D. Liang,[15] S. Liang,[15] X. Meng,[15] J. Tao,[15] X. Wang,[15] Z. Wang,[15] C. Asawatangtrakuldee,[16] Y. Ban,[16] Y. Guo,[16] Q. Li,[16] W. Li,[16] S. Liu,[16] Y. Mao,[16] S. J. Qian,[16] D. Wang,[16] L. Zhang,[16] W. Zou,[16] C. Avila,[17] C. A. Carrillo Montoya,[17] L. F. Chaparro Sierra,[17] J. P. Gomez,[17] B. Gomez Moreno,[17] J. C. Sanabria,[17] N. Godinovic,[18] D. Lelas,[18] R. Plestina,[18,i] D. Polic,[18] I. Puljak,[18] Z. Antunovic,[19] M. Kovac,[19] V. Brigljevic,[20] K. Kadija,[20] J. Luetic,[20] D. Mekterovic,[20] S. Morovic,[20] L. Tikvica,[20] A. Attikis,[21] G. Mavromanolakis,[21] J. Mousa,[21] C. Nicolaou,[21] F. Ptochos,[21] P. A. Razis,[21] M. Finger,[22]

M. Finger, Jr.,[22] A. A. Abdelalim,[23,j] Y. Assran,[23,k] S. Elgammal,[23,j] A. Ellithi Kamel,[23,l] M. A. Mahmoud,[23,m] A. Radi,[23,n,o] M. Kadastik,[24] M. Müntel,[24] M. Murumaa,[24] M. Raidal,[24] L. Rebane,[24] A. Tiko,[24] P. Eerola,[25] G. Fedi,[25] M. Voutilainen,[25] J. Härkönen,[26] V. Karimäki,[26] R. Kinnunen,[26] M. J. Kortelainen,[26] T. Lampén,[26] K. Lassila-Perini,[26] S. Lehti,[26] T. Lindén,[26] P. Luukka,[26] T. Mäenpää,[26] T. Peltola,[26] E. Tuominen,[26] J. Tuominiemi,[26] E. Tuovinen,[26] L. Wendland,[26] T. Tuuva,[27] M. Besancon,[28] F. Couderc,[28] M. Dejardin,[28] D. Denegri,[28] B. Fabbro,[28] J. L. Faure,[28] F. Ferri,[28] S. Ganjour,[28] A. Givernaud,[28] P. Gras,[28] G. Hamel de Monchenault,[28] P. Jarry,[28] E. Locci,[28] J. Malcles,[28] L. Millischer,[28] A. Nayak,[28] J. Rander,[28] A. Rosowsky,[28] M. Titov,[28] S. Baffioni,[29] F. Beaudette,[29] L. Benhabib,[29] M. Bluj,[29,p] P. Busson,[29] C. Charlot,[29] N. Daci,[29] T. Dahms,[29] M. Dalchenko,[29] L. Dobrzynski,[29] A. Florent,[29] R. Granier de Cassagnac,[29] M. Haguenauer,[29] P. Miné,[29] C. Mironov,[29] I. N. Naranjo,[29] M. Nguyen,[29] C. Ochando,[29] P. Paganini,[29] D. Sabes,[29] R. Salerno,[29] Y. Sirois,[29] C. Veelken,[29] A. Zabi,[29] J.-L. Agram,[30,q] J. Andrea,[30] D. Bloch,[30] J.-M. Brom,[30] E. C. Chabert,[30] C. Collard,[30] E. Conte,[30,q] F. Drouhin,[30,q] J.-C. Fontaine,[30,q] D. Gelé,[30] U. Goerlach,[30] C. Goetzmann,[30] P. Juillot,[30] A.-C. Le Bihan,[30] P. Van Hove,[30] S. Gadrat,[31] S. Beauceron,[32] N. Beaupere,[32] G. Boudoul,[32] S. Brochet,[32] J. Chasserat,[32] R. Chierici,[32] D. Contardo,[32] P. Depasse,[32] H. El Mamouni,[32] J. Fan,[32] J. Fay,[32] S. Gascon,[32] M. Gouzevitch,[32] B. Ille,[32] T. Kurca,[32] M. Lethuillier,[32] L. Mirabito,[32] S. Perries,[32] L. Sgandurra,[32] V. Sordini,[32] M. Vander Donckt,[32] P. Verdier,[32] S. Viret,[32] H. Xiao,[32] Z. Tsamalaidze,[33,r] C. Autermann,[34] S. Beranek,[34] M. Bontenackels,[34] B. Calpas,[34] M. Edelhoff,[34] L. Feld,[34] N. Heracleous,[34] O. Hindrichs,[34] K. Klein,[34] A. Ostapchuk,[34] A. Perieanu,[34] F. Raupach,[34] J. Sammet,[34] S. Schael,[34] D. Sprenger,[34] H. Weber,[34] B. Wittmer,[34] V. Zhukov,[34,f] M. Ata,[35] J. Caudron,[35] E. Dietz-Laursonn,[35] D. Duchardt,[35] M. Erdmann,[35] R. Fischer,[35] A. Güth,[35] T. Hebbeker,[35] C. Heidemann,[35] K. Hoepfner,[35] D. Klingebiel,[35] S. Knutzen,[35] P. Kreuzer,[35] M. Merschmeyer,[35] A. Meyer,[35] M. Olschewski,[35] K. Padeken,[35] P. Papacz,[35] H. Pieta,[35] H. Reithler,[35] S. A. Schmitz,[35] L. Sonnenschein,[35] J. Steggemann,[35] D. Teyssier,[35] S. Thüer,[35] M. Weber,[35] V. Cherepanov,[36] Y. Erdogan,[36] G. Flügge,[36] H. Geenen,[36] M. Geisler,[36] W. Haj Ahmad,[36] F. Hoehle,[36] B. Kargoll,[36] T. Kress,[36] Y. Kuessel,[36] J. Lingemann,[36,c] A. Nowack,[36] I. M. Nugent,[36] L. Perchalla,[36] O. Pooth,[36] A. Stahl,[36] I. Asin,[37] N. Bartosik,[37] J. Behr,[37] W. Behrenhoff,[37] U. Behrens,[37] A. J. Bell,[37] M. Bergholz,[37,s] A. Bethani,[37] K. Borras,[37] A. Burgmeier,[37] A. Cakir,[37] L. Calligaris,[37] A. Campbell,[37] S. Choudhury,[37] F. Costanza,[37] C. Diez Pardos,[37] S. Dooling,[37] T. Dorland,[37] G. Eckerlin,[37] D. Eckstein,[37] G. Flucke,[37] A. Geiser,[37] I. Glushkov,[37] A. Grebenyuk,[37] P. Gunnellini,[37] S. Habib,[37] J. Hauk,[37] G. Hellwig,[37] D. Horton,[37] H. Jung,[37] M. Kasemann,[37] P. Katsas,[37] C. Kleinwort,[37] H. Kluge,[37] M. Krämer,[37] D. Krücker,[37] E. Kuznetsova,[37] W. Lange,[37] J. Leonard,[37] K. Lipka,[37] W. Lohmann,[37,s] B. Lutz,[37] R. Mankel,[37] I. Marfin,[37] I.-A. Melzer-Pellmann,[37] A. B. Meyer,[37] J. Mnich,[37] A. Mussgiller,[37] S. Naumann-Emme,[37] O. Novgorodova,[37] F. Nowak,[37] J. Olzem,[37] H. Perrey,[37] A. Petrukhin,[37] D. Pitzl,[37] R. Placakyte,[37] A. Raspereza,[37] P. M. Ribeiro Cipriano,[37] C. Riedl,[37] E. Ron,[37] M. Ö. Sahin,[37] J. Salfeld-Nebgen,[37] R. Schmidt,[37,s] T. Schoerner-Sadenius,[37] N. Sen,[37] M. Stein,[37] R. Walsh,[37] C. Wissing,[37] M. Aldaya Martin,[38] V. Blobel,[38] H. Enderle,[38] J. Erfle,[38] E. Garutti,[38] U. Gebbert,[38] M. Görner,[38] M. Gosselink,[38] J. Haller,[38] K. Heine,[38] R. S. Höing,[38] G. Kaussen,[38] H. Kirschenmann,[38] R. Klanner,[38] R. Kogler,[38] J. Lange,[38] I. Marchesini,[38] T. Peiffer,[38] N. Pietsch,[38] D. Rathjens,[38] C. Sander,[38] H. Schettler,[38] P. Schleper,[38] E. Schlieckau,[38] A. Schmidt,[38] M. Schröder,[38] T. Schum,[38] M. Seidel,[38] J. Sibille,[38,t] V. Sola,[38] H. Stadie,[38] G. Steinbrück,[38] J. Thomsen,[38] D. Troendle,[38] E. Usai,[38] L. Vanelderen,[38] C. Barth,[39] C. Baus,[39] J. Berger,[39] C. Böser,[39] E. Butz,[39] T. Chwalek,[39] W. De Boer,[39] A. Descroix,[39] A. Dierlamm,[39] M. Feindt,[39] M. Guthoff,[39,c] F. Hartmann,[39,c] T. Hauth,[39,c] H. Held,[39] K. H. Hoffmann,[39] U. Husemann,[39] I. Katkov,[39,f] J. R. Komaragiri,[39] A. Kornmayer,[39,c] P. Lobelle Pardo,[39] D. Martschei,[39] M. U. Mozer,[39] Th. Müller,[39] M. Niegel,[39] A. Nürnberg,[39] O. Oberst,[39] J. Ott,[39] G. Quast,[39] K. Rabbertz,[39] F. Ratnikov,[39] S. Röcker,[39] F.-P. Schilling,[39] G. Schott,[39] H. J. Simonis,[39] F. M. Stober,[39] R. Ulrich,[39] J. Wagner-Kuhr,[39] S. Wayand,[39] T. Weiler,[39] M. Zeise,[39] G. Anagnostou,[40] G. Daskalakis,[40] T. Geralis,[40] S. Kesisoglou,[40] A. Kyriakis,[40] D. Loukas,[40] A. Markou,[40] C. Markou,[40] E. Ntomari,[40] I. Topsis-giotis,[40] L. Gouskos,[41] A. Panagiotou,[41] N. Saoulidou,[41] E. Stiliaris,[41] X. Aslanoglou,[42] I. Evangelou,[42] G. Flouris,[42] C. Foudas,[42] P. Kokkas,[42] N. Manthos,[42] I. Papadopoulos,[42] E. Paradas,[42] G. Bencze,[43] C. Hajdu,[43] P. Hidas,[43] D. Horvath,[43,u] F. Sikler,[43] V. Veszpremi,[43] G. Vesztergombi,[43,v] A. J. Zsigmond,[43] N. Beni,[44] S. Czellar,[44] J. Molnar,[44] J. Palinkas,[44] Z. Szillasi,[44] J. Karancsi,[45] P. Raics,[45] Z. L. Trocsanyi,[45] B. Ujvari,[45] S. K. Swain,[46,w] S. B. Beri,[47] V. Bhatnagar,[47] N. Dhingra,[47] R. Gupta,[47] M. Kaur,[47] M. Z. Mehta,[47] M. Mittal,[47] N. Nishu,[47] A. Sharma,[47] J. B. Singh,[47] Ashok Kumar,[48] Arun Kumar,[48] S. Ahuja,[48] A. Bhardwaj,[48] B. C. Choudhary,[48] A. Kumar,[48] S. Malhotra,[48] M. Naimuddin,[48] K. Ranjan,[48] P. Saxena,[48]

V. Sharma,[48] R. K. Shivpuri,[48] S. Banerjee,[49] S. Bhattacharya,[49] K. Chatterjee,[49] S. Dutta,[49] B. Gomber,[49] Sa. Jain,[49] Sh. Jain,[49] R. Khurana,[49] A. Modak,[49] S. Mukherjee,[49] D. Roy,[49] S. Sarkar,[49] M. Sharan,[49] A. P. Singh,[49] A. Abdulsalam,[50] D. Dutta,[50] S. Kailas,[50] V. Kumar,[50] A. K. Mohanty,[50,c] L. M. Pant,[50] P. Shukla,[50] A. Topkar,[50] T. Aziz,[51] R. M. Chatterjee,[51] S. Ganguly,[51] S. Ghosh,[51] M. Guchait,[51,x] A. Gurtu,[51,y] G. Kole,[51] S. Kumar,[51] M. Maity,[51,z] G. Majumder,[51] K. Mazumdar,[51] G. B. Mohanty,[51] B. Parida,[51] K. Sudhakar,[51] N. Wickramage,[51,aa] S. Banerjee,[52] S. Dugad,[52] H. Arfaei,[53] H. Bakhshiansohi,[53] S. M. Etesami,[53,bb] A. Fahim,[53,cc] A. Jafari,[53] M. Khakzad,[53] M. Mohammadi Najafabadi,[53] S. Paktinat Mehdiabadi,[53] B. Safarzadeh,[53,dd] M. Zeinali,[53] M. Grunewald,[54] M. Abbrescia,[55a,55b] L. Barbone,[55a,55b] C. Calabria,[55a,55b] S. S. Chhibra,[55a,55b] A. Colaleo,[55a] D. Creanza,[55a,55c] N. De Filippis,[55a,55c] M. De Palma,[55a,55b] L. Fiore,[55a] G. Iaselli,[55a,55c] G. Maggi,[55a,55c] M. Maggi,[55a] B. Marangelli,[55a,55b] S. My,[55a,55c] S. Nuzzo,[55a,55b] N. Pacifico,[55a] A. Pompili,[55a,55b] G. Pugliese,[55a,55c] G. Selvaggi,[55a,55b] L. Silvestris,[55a] G. Singh,[55a,55b] R. Venditti,[55a,55b] P. Verwilligen,[55a] G. Zito,[55a] G. Abbiendi,[56a] A. C. Benvenuti,[56a] D. Bonacorsi,[56a,56b] S. Braibant-Giacomelli,[56a,56b] L. Brigliadori,[56a,56b] R. Campanini,[56a,56b] P. Capiluppi,[56a,56b] A. Castro,[56a,56b] F. R. Cavallo,[56a] G. Codispoti,[56a,56b] M. Cuffiani,[56a,56b] G. M. Dallavalle,[56a] F. Fabbri,[56a] A. Fanfani,[56a,56b] D. Fasanella,[56a,56b] P. Giacomelli,[56a] C. Grandi,[56a] L. Guiducci,[56a,56b] S. Marcellini,[56a] G. Masetti,[56a] M. Meneghelli,[56a,56b] A. Montanari,[56a] F. L. Navarria,[56a,56b] F. Odorici,[56a] A. Perrotta,[56a] F. Primavera,[56a,56b] A. M. Rossi,[56a,56b] T. Rovelli,[56a,56b] G. P. Siroli,[56a,56b] N. Tosi,[56a,56b] R. Travaglini,[56a,56b] S. Albergo,[57a,57b] M. Chiorboli,[57a,57b] S. Costa,[57a,57b] F. Giordano,[57a,c] R. Potenza,[57a,57b] A. Tricomi,[57a,57b] C. Tuve,[57a,57b] G. Barbagli,[58a] V. Ciulli,[58a,58b] C. Civinini,[58a] R. D'Alessandro,[58a,58b] E. Focardi,[58a,58b] S. Frosali,[58a,58b] E. Gallo,[58a] S. Gonzi,[58a,58b] V. Gori,[58a,58b] P. Lenzi,[58a,58b] M. Meschini,[58a] S. Paoletti,[58a] G. Sguazzoni,[58a] A. Tropiano,[58a,58b] L. Benussi,[59] S. Bianco,[59] F. Fabbri,[59] D. Piccolo,[59] P. Fabbricatore,[60a] R. Ferretti,[60a,60b] F. Ferro,[60a] M. Lo Vetere,[60a,60b] R. Musenich,[60a] E. Robutti,[60a] S. Tosi,[60a,60b] A. Benaglia,[61a] M. E. Dinardo,[61a,61b] S. Fiorendi,[61a,61b] S. Gennai,[61a] A. Ghezzi,[61a,61b] P. Govoni,[61a,61b] M. T. Lucchini,[61a,61b,c] S. Malvezzi,[61a] R. A. Manzoni,[61a,61b,c] A. Martelli,[61a,61b,c] D. Menasce,[61a] L. Moroni,[61a] M. Paganoni,[61a,61b] D. Pedrini,[61a] S. Ragazzi,[61a,61b] N. Redaelli,[61a] T. Tabarelli de Fatis,[61a,61b] S. Buontempo,[62a] N. Cavallo,[62a,62c] A. De Cosa,[62a,62b] F. Fabozzi,[62a,62c] A. O. M. Iorio,[62a,62b] L. Lista,[62a] S. Meola,[62a,62d,c] M. Merola,[62a] P. Paolucci,[62a,c] P. Azzi,[63a] N. Bacchetta,[63a] P. Bellan,[63a,63b] M. Biasotto,[63a,ee] D. Bisello,[63a,63b] A. Branca,[63a,63b] R. Carlin,[63a,63b] P. Checchia,[63a] T. Dorigo,[63a] U. Dosselli,[63a] M. Galanti,[63a,63b,c] F. Gasparini,[63a,63b] U. Gasparini,[63a,63b] P. Giubilato,[63a,63b] A. Gozzelino,[63a] K. Kanishchev,[63a,63c] S. Lacaprara,[63a] I. Lazzizzera,[63a,63c] M. Margoni,[63a,63b] A. T. Meneguzzo,[63a,63b] M. Nespolo,[63a] J. Pazzini,[63a,63b] N. Pozzobon,[63a,63b] P. Ronchese,[63a,63b] F. Simonetto,[63a,63b] E. Torassa,[63a] M. Tosi,[63a,63b] S. Ventura,[63a] P. Zotto,[63a,63b] A. Zucchetta,[63a,63b] G. Zumerle,[63a,63b] M. Gabusi,[64a,64b] S. P. Ratti,[64a,64b] C. Riccardi,[64a,64b] P. Vitulo,[64a,64b] M. Biasini,[65a,65b] G. M. Bilei,[65a] L. Fanò,[65a,65b] P. Lariccia,[65a,65b] G. Mantovani,[65a,65b] M. Menichelli,[65a] A. Nappi,[65a,65b,a] F. Romeo,[65a,65b] A. Saha,[65a] A. Santocchia,[65a,65b] A. Spiezia,[65a,65b] K. Androsov,[66a,ff] P. Azzurri,[66a] G. Bagliesi,[66a] J. Bernardini,[66a] T. Boccali,[66a] G. Broccolo,[66a,66c] R. Castaldi,[66a] M. A. Ciocci,[66a] R. T. D'Agnolo,[66a,66c,c] R. Dell'Orso,[66a] F. Fiori,[66a,66c] L. Foà,[66a,66c] A. Giassi,[66a] M. T. Grippo,[66a,ff] A. Kraan,[66a] F. Ligabue,[66a,66c] T. Lomtadze,[66a] L. Martini,[66a,ff] A. Messineo,[66a,66b] C. S. Moon,[66a] F. Palla,[66a] A. Rizzi,[66a,66b] A. Savoy-Navarro,[66a,gg] A. T. Serban,[66a] P. Spagnolo,[66a] P. Squillacioti,[66a] R. Tenchini,[66a] G. Tonelli,[66a,66b] A. Venturi,[66a] P. G. Verdini,[66a] C. Vernieri,[66a,66c] L. Barone,[67a,67b] F. Cavallari,[67a] D. Del Re,[67a,67b] M. Diemoz,[67a] M. Grassi,[67a,67b] E. Longo,[67a,67b] F. Margaroli,[67a,67b] P. Meridiani,[67a] F. Micheli,[67a,67b] S. Nourbakhsh,[67a,67b] G. Organtini,[67a,67b] R. Paramatti,[67a] S. Rahatlou,[67a,67b] C. Rovelli,[67a] L. Soffi,[67a,67b] N. Amapane,[68a,68b] R. Arcidiacono,[68a,68c] S. Argiro,[68a,68b] M. Arneodo,[68a,68c] R. Bellan,[68a,68b] C. Biino,[68a] N. Cartiglia,[68a] S. Casasso,[68a,68b] M. Costa,[68a,68b] A. Degano,[68a,68b] N. Demaria,[68a] C. Mariotti,[68a] S. Maselli,[68a] E. Migliore,[68a,68b] V. Monaco,[68a,68b] M. Musich,[68a] M. M. Obertino,[68a,68c] N. Pastrone,[68a] M. Pelliccioni,[68a,c] A. Potenza,[68a,68b] A. Romero,[68a,68b] M. Ruspa,[68a,68c] R. Sacchi,[68a,68b] A. Solano,[68a,68b] A. Staiano,[68a] U. Tamponi,[68a] S. Belforte,[69a] V. Candelise,[69a,69b] M. Casarsa,[69a] F. Cossutti,[69a,c] G. Della Ricca,[69a,69b] B. Gobbo,[69a] C. La Licata,[69a,69b] M. Marone,[69a,69b] D. Montanino,[69a,69b] A. Penzo,[69a] A. Schizzi,[69a,69b] A. Zanetti,[69a] S. Chang,[70] T. Y. Kim,[70] S. K. Nam,[70] D. H. Kim,[71] G. N. Kim,[71] J. E. Kim,[71] D. J. Kong,[71] S. Lee,[71] Y. D. Oh,[71] H. Park,[71] D. C. Son,[71] J. Y. Kim,[72] Zero J. Kim,[72] S. Song,[72] S. Choi,[73] D. Gyun,[73] B. Hong,[73] M. Jo,[73] H. Kim,[73] T. J. Kim,[73] K. S. Lee,[73] S. K. Park,[73] Y. Roh,[73] M. Choi,[74] J. H. Kim,[74] C. Park,[74] I. C. Park,[74] S. Park,[74] G. Ryu,[74] Y. Choi,[75] Y. K. Choi,[75] J. Goh,[75] M. S. Kim,[75] E. Kwon,[75] B. Lee,[75] J. Lee,[75] S. Lee,[75] H. Seo,[75] I. Yu,[75] I. Grigelionis,[76] A. Juodagalvis,[76] H. Castilla-Valdez,[77] E. De La Cruz-Burelo,[77] I. Heredia-de La Cruz,[77,hh] R. Lopez-Fernandez,[77] J. Martínez-Ortega,[77] A. Sanchez-Hernandez,[77] L. M. Villasenor-Cendejas,[77] S. Carrillo Moreno,[78]

F. Vazquez Valencia,[78] H. A. Salazar Ibarguen,[79] E. Casimiro Linares,[80] A. Morelos Pineda,[80] M. A. Reyes-Santos,[80] D. Krofcheck,[81] P. H. Butler,[82] R. Doesburg,[82] S. Reucroft,[82] H. Silverwood,[82] M. Ahmad,[83] M. I. Asghar,[83] J. Butt,[83] H. R. Hoorani,[83] S. Khalid,[83] W. A. Khan,[83] T. Khurshid,[83] S. Qazi,[83] M. A. Shah,[83] M. Shoaib,[83] H. Bialkowska,[84] B. Boimska,[84] T. Frueboes,[84] M. Górski,[84] M. Kazana,[84] K. Nawrocki,[84] K. Romanowska-Rybinska,[84] M. Szleper,[84] G. Wrochna,[84] P. Zalewski,[84] G. Brona,[85] K. Bunkowski,[85] M. Cwiok,[85] W. Dominik,[85] K. Doroba,[85] A. Kalinowski,[85] M. Konecki,[85] J. Krolikowski,[85] M. Misiura,[85] W. Wolszczak,[85] N. Almeida,[86] P. Bargassa,[86] C. Beirão Da Cruz E Silva,[86] P. Faccioli,[86] P. G. Ferreira Parracho,[86] M. Gallinaro,[86] F. Nguyen,[86] J. Rodrigues Antunes,[86] J. Seixas,[86,c] J. Varela,[86] P. Vischia,[86] S. Afanasiev,[87] P. Bunin,[87] M. Gavrilenko,[87] I. Golutvin,[87] I. Gorbunov,[87] A. Kamenev,[87] V. Karjavin,[87] V. Konoplyanikov,[87] A. Lanev,[87] A. Malakhov,[87] V. Matveev,[87] P. Moisenz,[87] V. Palichik,[87] V. Perelygin,[87] S. Shmatov,[87] N. Skatchkov,[87] V. Smirnov,[87] A. Zarubin,[87] S. Evstyukhin,[88] V. Golovtsov,[88] Y. Ivanov,[88] V. Kim,[88] P. Levchenko,[88] V. Murzin,[88] V. Oreshkin,[88] I. Smirnov,[88] V. Sulimov,[88] L. Uvarov,[88] S. Vavilov,[88] A. Vorobyev,[88] An. Vorobyev,[88] Yu. Andreev,[89] A. Dermenev,[89] S. Gninenko,[89] N. Golubev,[89] M. Kirsanov,[89] N. Krasnikov,[89] A. Pashenkov,[89] D. Tlisov,[89] A. Toropin,[89] V. Epshteyn,[90] M. Erofeeva,[90] V. Gavrilov,[90] N. Lychkovskaya,[90] V. Popov,[90] G. Safronov,[90] S. Semenov,[90] A. Spiridonov,[90] V. Stolin,[90] E. Vlasov,[90] A. Zhokin,[90] V. Andreev,[91] M. Azarkin,[91] I. Dremin,[91] M. Kirakosyan,[91] A. Leonidov,[91] G. Mesyats,[91] S. V. Rusakov,[91] A. Vinogradov,[91] A. Belyaev,[92] E. Boos,[92] V. Bunichev,[92] M. Dubinin,[92,h] L. Dudko,[92] A. Ershov,[92] V. Klyukhin,[92] I. Lokhtin,[92] A. Markina,[92] S. Obraztsov,[92] M. Perfilov,[92] S. Petrushanko,[92] V. Savrin,[92] N. Tsirova,[92] I. Azhgirey,[93] I. Bayshev,[93] S. Bitioukov,[93] V. Kachanov,[93] A. Kalinin,[93] D. Konstantinov,[93] V. Krychkine,[93] V. Petrov,[93] R. Ryutin,[93] A. Sobol,[93] L. Tourtchanovitch,[93] S. Troshin,[93] N. Tyurin,[93] A. Uzunian,[93] A. Volkov,[93] P. Adzic,[94,ii] M. Djordjevic,[94] M. Ekmedzic,[94] D. Krpic,[94,ii] J. Milosevic,[94] M. Aguilar-Benitez,[95] J. Alcaraz Maestre,[95] C. Battilana,[95] E. Calvo,[95] M. Cerrada,[95] M. Chamizo Llatas,[95,c] N. Colino,[95] B. De La Cruz,[95] A. Delgado Peris,[95] D. Domínguez Vázquez,[95] C. Fernandez Bedoya,[95] J. P. Fernández Ramos,[95] A. Ferrando,[95] J. Flix,[95] M. C. Fouz,[95] P. Garcia-Abia,[95] O. Gonzalez Lopez,[95] S. Goy Lopez,[95] J. M. Hernandez,[95] M. I. Josa,[95] G. Merino,[95] E. Navarro De Martino,[95] J. Puerta Pelayo,[95] A. Quintario Olmeda,[95] I. Redondo,[95] L. Romero,[95] J. Santaolalla,[95] M. S. Soares,[95] C. Willmott,[95] C. Albajar,[96] J. F. de Trocóniz,[96] H. Brun,[97] J. Cuevas,[97] J. Fernandez Menendez,[97] S. Folgueras,[97] I. Gonzalez Caballero,[97] L. Lloret Iglesias,[97] J. Piedra Gomez,[97] J. A. Brochero Cifuentes,[98] I. J. Cabrillo,[98] A. Calderon,[98] S. H. Chuang,[98] J. Duarte Campderros,[98] M. Fernandez,[98] G. Gomez,[98] J. Gonzalez Sanchez,[98] A. Graziano,[98] C. Jorda,[98] A. Lopez Virto,[98] J. Marco,[98] R. Marco,[98] C. Martinez Rivero,[98] F. Matorras,[98] F. J. Munoz Sanchez,[98] T. Rodrigo,[98] A. Y. Rodríguez-Marrero,[98] A. Ruiz-Jimeno,[98] L. Scodellaro,[98] I. Vila,[98] R. Vilar Cortabitarte,[98] D. Abbaneo,[99] E. Auffray,[99] G. Auzinger,[99] M. Bachtis,[99] P. Baillon,[99] A. H. Ball,[99] D. Barney,[99] J. Bendavid,[99] J. F. Benitez,[99] C. Bernet,[99,i] G. Bianchi,[99] P. Bloch,[99] A. Bocci,[99] A. Bonato,[99] O. Bondu,[99] C. Botta,[99] H. Breuker,[99] T. Camporesi,[99] G. Cerminara,[99] T. Christiansen,[99] J. A. Coarasa Perez,[99] S. Colafranceschi,[99,jj] M. D'Alfonso,[99] D. d'Enterria,[99] A. Dabrowski,[99] A. David,[99] F. De Guio,[99] A. De Roeck,[99] S. De Visscher,[99] S. Di Guida,[99] M. Dobson,[99] N. Dupont-Sagorin,[99] A. Elliott-Peisert,[99] J. Eugster,[99] G. Franzoni,[99] W. Funk,[99] G. Georgiou,[99] M. Giffels,[99] D. Gigi,[99] K. Gill,[99] D. Giordano,[99] M. Girone,[99] M. Giunta,[99] F. Glege,[99] R. Gomez-Reino Garrido,[99] S. Gowdy,[99] R. Guida,[99] J. Hammer,[99] M. Hansen,[99] P. Harris,[99] C. Hartl,[99] A. Hinzmann,[99] V. Innocente,[99] P. Janot,[99] E. Karavakis,[99] K. Kousouris,[99] K. Krajczar,[99] P. Lecoq,[99] Y.-J. Lee,[99] C. Lourenço,[99] N. Magini,[99] L. Malgeri,[99] M. Mannelli,[99] L. Masetti,[99] F. Meijers,[99] S. Mersi,[99] E. Meschi,[99] R. Moser,[99] M. Mulders,[99] P. Musella,[99] E. Nesvold,[99] L. Orsini,[99] E. Palencia Cortezon,[99] E. Perez,[99] L. Perrozzi,[99] A. Petrilli,[99] A. Pfeiffer,[99] M. Pierini,[99] M. Pimiä,[99] D. Piparo,[99] M. Plagge,[99] L. Quertenmont,[99] A. Racz,[99] W. Reece,[99] G. Rolandi,[99,kk] M. Rovere,[99] H. Sakulin,[99] F. Santanastasio,[99] C. Schäfer,[99] C. Schwick,[99] S. Sekmen,[99] A. Sharma,[99] P. Siegrist,[99] P. Silva,[99] M. Simon,[99] P. Sphicas,[99,ll] D. Spiga,[99] M. Stoye,[99] A. Tsirou,[99] G. I. Veres,[99,v] J. R. Vlimant,[99] H. K. Wöhri,[99] S. D. Worm,[99,mm] W. D. Zeuner,[99] W. Bertl,[100] K. Deiters,[100] W. Erdmann,[100] K. Gabathuler,[100] R. Horisberger,[100] Q. Ingram,[100] H. C. Kaestli,[100] S. König,[100] D. Kotlinski,[100] U. Langenegger,[100] D. Renker,[100] T. Rohe,[100] F. Bachmair,[101] L. Bäni,[101] L. Bianchini,[101] P. Bortignon,[101] M. A. Buchmann,[101] B. Casal,[101] N. Chanon,[101] A. Deisher,[101] G. Dissertori,[101] M. Dittmar,[101] M. Donegà,[101] M. Dünser,[101] P. Eller,[101] K. Freudenreich,[101] C. Grab,[101] D. Hits,[101] P. Lecomte,[101] W. Lustermann,[101] B. Mangano,[101] A. C. Marini,[101] P. Martinez Ruiz del Arbol,[101] D. Meister,[101] N. Mohr,[101] F. Moortgat,[101] C. Nägeli,[101,nn] P. Nef,[101] F. Nessi-Tedaldi,[101] F. Pandolfi,[101] L. Pape,[101] F. Pauss,[101] M. Peruzzi,[101] M. Quittnat,[101] F. J. Ronga,[101] M. Rossini,[101] L. Sala,[101] A. K. Sanchez,[101] A. Starodumov,[101,oo] B. Stieger,[101] M. Takahashi,[101] L. Tauscher,[101,a]

A. Thea,[101] K. Theofilatos,[101] D. Treille,[101] C. Urscheler,[101] R. Wallny,[101] H. A. Weber,[101] C. Amsler,[102,pp] V. Chiochia,[102] C. Favaro,[102] M. Ivova Rikova,[102] B. Kilminster,[102] B. Millan Mejias,[102] P. Robmann,[102] H. Snoek,[102] S. Taroni,[102] M. Verzetti,[102] Y. Yang,[102] M. Cardaci,[103] K. H. Chen,[103] C. Ferro,[103] C. M. Kuo,[103] S. W. Li,[103] W. Lin,[103] Y. J. Lu,[103] R. Volpe,[103] S. S. Yu,[103] P. Bartalini,[104] P. Chang,[104] Y. H. Chang,[104] Y. W. Chang,[104] Y. Chao,[104] K. F. Chen,[104] C. Dietz,[104] U. Grundler,[104] W.-S. Hou,[104] Y. Hsiung,[104] K. Y. Kao,[104] Y. J. Lei,[104] R.-S. Lu,[104] D. Majumder,[104] E. Petrakou,[104] X. Shi,[104] J. G. Shiu,[104] Y. M. Tzeng,[104] M. Wang,[104] B. Asavapibhop,[105] N. Suwonjandee,[105] A. Adiguzel,[106] M. N. Bakirci,[106,qq] S. Cerci,[106,rr] C. Dozen,[106] I. Dumanoglu,[106] E. Eskut,[106] S. Girgis,[106] G. Gokbulut,[106] E. Gurpinar,[106] I. Hos,[106] E. E. Kangal,[106] A. Kayis Topaksu,[106] G. Onengut,[106,ss] K. Ozdemir,[106] S. Ozturk,[106,qq] A. Polatoz,[106] K. Sogut,[106,tt] D. Sunar Cerci,[106,rr] B. Tali,[106,rr] H. Topakli,[106,qq] M. Vergili,[106] I. V. Akin,[107] T. Aliev,[107] B. Bilin,[107] S. Bilmis,[107] M. Deniz,[107] H. Gamsizkan,[107] A. M. Guler,[107] G. Karapinar,[107,uu] K. Ocalan,[107] A. Ozpineci,[107] M. Serin,[107] R. Sever,[107] U. E. Surat,[107] M. Yalvac,[107] M. Zeyrek,[107] E. Gülmez,[108] B. Isildak,[108,vv] M. Kaya,[108,ww] O. Kaya,[108,ww] S. Ozkorucuklu,[108,xx] N. Sonmez,[108,yy] H. Bahtiyar,[109,zz] E. Barlas,[109] K. Cankocak,[109] Y. O. Günaydin,[109,aaa] F. I. Vardarı,[109] M. Yücel,[109] L. Levchuk,[110] P. Sorokin,[110] J. J. Brooke,[111] E. Clement,[111] D. Cussans,[111] H. Flacher,[111] R. Frazier,[111] J. Goldstein,[111] M. Grimes,[111] G. P. Heath,[111] H. F. Heath,[111] L. Kreczko,[111] C. Lucas,[111] Z. Meng,[111] S. Metson,[111] D. M. Newbold,[111,mm] K. Nirunpong,[111] S. Paramesvaran,[111] A. Poll,[111] S. Senkin,[111] V. J. Smith,[111] T. Williams,[111] K. W. Bell,[112] A. Belyaev,[112,bbb] C. Brew,[112] R. M. Brown,[112] D. J. A. Cockerill,[112] J. A. Coughlan,[112] K. Harder,[112] S. Harper,[112] J. Ilic,[112] E. Olaiya,[112] D. Petyt,[112] B. C. Radburn-Smith,[112] C. H. Shepherd-Themistocleous,[112] I. R. Tomalin,[112] W. J. Womersley,[112] R. Bainbridge,[113] O. Buchmuller,[113] D. Burton,[113] D. Colling,[113] N. Cripps,[113] M. Cutajar,[113] P. Dauncey,[113] G. Davies,[113] M. Della Negra,[113] W. Ferguson,[113] J. Fulcher,[113] D. Futyan,[113] A. Gilbert,[113] A. Guneratne Bryer,[113] G. Hall,[113] Z. Hatherell,[113] J. Hays,[113] G. Iles,[113] M. Jarvis,[113] G. Karapostoli,[113] M. Kenzie,[113] R. Lane,[113] R. Lucas,[113,mm] L. Lyons,[113] A.-M. Magnan,[113] J. Marrouche,[113] B. Mathias,[113] R. Nandi,[113] J. Nash,[113] A. Nikitenko,[113,oo] J. Pela,[113] M. Pesaresi,[113] K. Petridis,[113] M. Pioppi,[113,ccc] D. M. Raymond,[113] S. Rogerson,[113] A. Rose,[113] C. Seez,[113] P. Sharp,[113,a] A. Sparrow,[113] A. Tapper,[113] M. Vazquez Acosta,[113] T. Virdee,[113] S. Wakefield,[113] N. Wardle,[113] M. Chadwick,[114] J. E. Cole,[114] P. R. Hobson,[114] A. Khan,[114] P. Kyberd,[114] D. Leggat,[114] D. Leslie,[114] W. Martin,[114] I. D. Reid,[114] P. Symonds,[114] L. Teodorescu,[114] M. Turner,[114] J. Dittmann,[115] K. Hatakeyama,[115] A. Kasmi,[115] H. Liu,[115] T. Scarborough,[115] O. Charaf,[116] S. I. Cooper,[116] C. Henderson,[116] P. Rumerio,[116] A. Avetisyan,[117] T. Bose,[117] C. Fantasia,[117] A. Heister,[117] P. Lawson,[117] D. Lazic,[117] J. Rohlf,[117] D. Sperka,[117] J. St. John,[117] L. Sulak,[117] J. Alimena,[118] S. Bhattacharya,[118] G. Christopher,[118] D. Cutts,[118] Z. Demiragli,[118] A. Ferapontov,[118] A. Garabedian,[118] U. Heintz,[118] S. Jabeen,[118] G. Kukartsev,[118] E. Laird,[118] G. Landsberg,[118] M. Luk,[118] M. Narain,[118] M. Segala,[118] T. Sinthuprasith,[118] T. Speer,[118] R. Breedon,[119] G. Breto,[119] M. Calderon De La Barca Sanchez,[119] S. Chauhan,[119] M. Chertok,[119] J. Conway,[119] R. Conway,[119] P. T. Cox,[119] R. Erbacher,[119] M. Gardner,[119] R. Houtz,[119] W. Ko,[119] A. Kopecky,[119] R. Lander,[119] T. Miceli,[119] D. Pellett,[119] J. Pilot,[119] F. Ricci-Tam,[119] B. Rutherford,[119] M. Searle,[119] J. Smith,[119] M. Squires,[119] M. Tripathi,[119] S. Wilbur,[119] R. Yohay,[119] V. Andreev,[120] D. Cline,[120] R. Cousins,[120] S. Erhan,[120] P. Everaerts,[120] C. Farrell,[120] M. Felcini,[120] J. Hauser,[120] M. Ignatenko,[120] C. Jarvis,[120] G. Rakness,[120] P. Schlein,[120,a] E. Takasugi,[120] P. Traczyk,[120] V. Valuev,[120] M. Weber,[120] J. Babb,[121] R. Clare,[121] J. Ellison,[121] J. W. Gary,[121] G. Hanson,[121] J. Heilman,[121] P. Jandir,[121] H. Liu,[121] O. R. Long,[121] A. Luthra,[121] M. Malberti,[121] H. Nguyen,[121] A. Shrinivas,[121] J. Sturdy,[121] S. Sumowidagdo,[121] R. Wilken,[121] S. Wimpenny,[121] W. Andrews,[122] J. G. Branson,[122] G. B. Cerati,[122] S. Cittolin,[122] D. Evans,[122] A. Holzner,[122] R. Kelley,[122] M. Lebourgeois,[122] J. Letts,[122] I. Macneill,[122] S. Padhi,[122] C. Palmer,[122] G. Petrucciani,[122] M. Pieri,[122] M. Sani,[122] V. Sharma,[122] S. Simon,[122] E. Sudano,[122] M. Tadel,[122] Y. Tu,[122] A. Vartak,[122] S. Wasserbaech,[122,ddd] F. Würthwein,[122] A. Yagil,[122] J. Yoo,[122] D. Barge,[123] C. Campagnari,[123] T. Danielson,[123] K. Flowers,[123] P. Geffert,[123] C. George,[123] F. Golf,[123] J. Incandela,[123] C. Justus,[123] D. Kovalskyi,[123] V. Krutelyov,[123] S. Lowette,[123] R. Magaña Villalba,[123] N. Mccoll,[123] V. Pavlunin,[123] J. Richman,[123] R. Rossin,[123] D. Stuart,[123] W. To,[123] C. West,[123] A. Apresyan,[124] A. Bornheim,[124] J. Bunn,[124] Y. Chen,[124] E. Di Marco,[124] J. Duarte,[124] D. Kcira,[124] Y. Ma,[124] A. Mott,[124] H. B. Newman,[124] C. Pena,[124] C. Rogan,[124] M. Spiropulu,[124] V. Timciuc,[124] J. Veverka,[124] R. Wilkinson,[124] S. Xie,[124] R. Y. Zhu,[124] V. Azzolini,[125] A. Calamba,[125] R. Carroll,[125] T. Ferguson,[125] Y. Iiyama,[125] D. W. Jang,[125] Y. F. Liu,[125] M. Paulini,[125] J. Russ,[125] H. Vogel,[125] I. Vorobiev,[125] J. P. Cumalat,[126] B. R. Drell,[126] W. T. Ford,[126] A. Gaz,[126] E. Luiggi Lopez,[126] U. Nauenberg,[126] J. G. Smith,[126] K. Stenson,[126] K. A. Ulmer,[126] S. R. Wagner,[126] J. Alexander,[127] A. Chatterjee,[127] N. Eggert,[127] L. K. Gibbons,[127]

W. Hopkins,[127] A. Khukhunaishvili,[127] B. Kreis,[127] N. Mirman,[127] G. Nicolas Kaufman,[127] J. R. Patterson,[127] A. Ryd,[127] E. Salvati,[127] W. Sun,[127] W. D. Teo,[127] J. Thom,[127] J. Thompson,[127] J. Tucker,[127] Y. Weng,[127] L. Winstrom,[127] P. Wittich,[127] D. Winn,[128] S. Abdullin,[129] M. Albrow,[129] J. Anderson,[129] G. Apollinari,[129] L. A. T. Bauerdick,[129] A. Beretvas,[129] J. Berryhill,[129] P. C. Bhat,[129] K. Burkett,[129] J. N. Butler,[129] V. Chetluru,[129] H. W. K. Cheung,[129] F. Chlebana,[129] S. Cihangir,[129] V. D. Elvira,[129] I. Fisk,[129] J. Freeman,[129] Y. Gao,[129] E. Gottschalk,[129] L. Gray,[129] D. Green,[129] O. Gutsche,[129] D. Hare,[129] R. M. Harris,[129] J. Hirschauer,[129] B. Hooberman,[129] S. Jindariani,[129] M. Johnson,[129] U. Joshi,[129] K. Kaadze,[129] B. Klima,[129] S. Kunori,[129] S. Kwan,[129] J. Linacre,[129] D. Lincoln,[129] R. Lipton,[129] J. Lykken,[129] K. Maeshima,[129] J. M. Marraffino,[129] V. I. Martinez Outschoorn,[129] S. Maruyama,[129] D. Mason,[129] P. McBride,[129] K. Mishra,[129] S. Mrenna,[129] Y. Musienko,[129,eee] C. Newman-Holmes,[129] V. O'Dell,[129] O. Prokofyev,[129] N. Ratnikova,[129] E. Sexton-Kennedy,[129] S. Sharma,[129] W. J. Spalding,[129] L. Spiegel,[129] L. Taylor,[129] S. Tkaczyk,[129] N. V. Tran,[129] L. Uplegger,[129] E. W. Vaandering,[129] R. Vidal,[129] J. Whitmore,[129] W. Wu,[129] F. Yang,[129] J. C. Yun,[129] D. Acosta,[130] P. Avery,[130] D. Bourilkov,[130] M. Chen,[130] T. Cheng,[130] S. Das,[130] M. De Gruttola,[130] G. P. Di Giovanni,[130] D. Dobur,[130] A. Drozdetskiy,[130] R. D. Field,[130] M. Fisher,[130] Y. Fu,[130] I. K. Furic,[130] J. Hugon,[130] B. Kim,[130] J. Konigsberg,[130] A. Korytov,[130] A. Kropivnitskaya,[130] T. Kypreos,[130] J. F. Low,[130] K. Matchev,[130] P. Milenovic,[130,fff] G. Mitselmakher,[130] L. Muniz,[130] R. Remington,[130] A. Rinkevicius,[130] N. Skhirtladze,[130] M. Snowball,[130] J. Yelton,[130] M. Zakaria,[130] V. Gaultney,[131] S. Hewamanage,[131] S. Linn,[131] P. Markowitz,[131] G. Martinez,[131] J. L. Rodriguez,[131] T. Adams,[132] A. Askew,[132] J. Bochenek,[132] J. Chen,[132] B. Diamond,[132] J. Haas,[132] S. Hagopian,[132] V. Hagopian,[132] K. F. Johnson,[132] H. Prosper,[132] V. Veeraraghavan,[132] M. Weinberg,[132] M. M. Baarmand,[133] B. Dorney,[133] M. Hohlmann,[133] H. Kalakhety,[133] F. Yumiceva,[133] M. R. Adams,[134] L. Apanasevich,[134] V. E. Bazterra,[134] R. R. Betts,[134] I. Bucinskaite,[134] J. Callner,[134] R. Cavanaugh,[134] O. Evdokimov,[134] L. Gauthier,[134] C. E. Gerber,[134] D. J. Hofman,[134] S. Khalatyan,[134] P. Kurt,[134] F. Lacroix,[134] D. H. Moon,[134] C. O'Brien,[134] C. Silkworth,[134] D. Strom,[134] P. Turner,[134] N. Varelas,[134] U. Akgun,[135] E. A. Albayrak,[135,zz] B. Bilki,[135,ggg] W. Clarida,[135] K. Dilsiz,[135] F. Duru,[135] S. Griffiths,[135] J.-P. Merlo,[135] H. Mermerkaya,[135,hhh] A. Mestvirishvili,[135] A. Moeller,[135] J. Nachtman,[135] C. R. Newsom,[135] H. Ogul,[135] Y. Onel,[135] F. Ozok,[135,zz] S. Sen,[135] P. Tan,[135] E. Tiras,[135] J. Wetzel,[135] T. Yetkin,[135,iii] K. Yi,[135] B. A. Barnett,[136] B. Blumenfeld,[136] S. Bolognesi,[136] G. Giurgiu,[136] A. V. Gritsan,[136] G. Hu,[136] P. Maksimovic,[136] C. Martin,[136] M. Swartz,[136] A. Whitbeck,[136] P. Baringer,[137] A. Bean,[137] G. Benelli,[137] R. P. Kenny III,[137] M. Murray,[137] D. Noonan,[137] S. Sanders,[137] R. Stringer,[137] J. S. Wood,[137] A. F. Barfuss,[138] I. Chakaberia,[138] A. Ivanov,[138] S. Khalil,[138] M. Makouski,[138] Y. Maravin,[138] L. K. Saini,[138] S. Shrestha,[138] I. Svintradze,[138] J. Gronberg,[139] D. Lange,[139] F. Rebassoo,[139] D. Wright,[139] A. Baden,[140] B. Calvert,[140] S. C. Eno,[140] J. A. Gomez,[140] N. J. Hadley,[140] R. G. Kellogg,[140] T. Kolberg,[140] Y. Lu,[140] M. Marionneau,[140] A. C. Mignerey,[140] K. Pedro,[140] A. Peterman,[140] A. Skuja,[140] J. Temple,[140] M. B. Tonjes,[140] S. C. Tonwar,[140] A. Apyan,[141] G. Bauer,[141] W. Busza,[141] I. A. Cali,[141] M. Chan,[141] L. Di Matteo,[141] V. Dutta,[141] G. Gomez Ceballos,[141] M. Goncharov,[141] D. Gulhan,[141] Y. Kim,[141] M. Klute,[141] Y. S. Lai,[141] A. Levin,[141] P. D. Luckey,[141] T. Ma,[141] S. Nahn,[141] C. Paus,[141] D. Ralph,[141] C. Roland,[141] G. Roland,[141] G. S. F. Stephans,[141] F. Stöckli,[141] K. Sumorok,[141] D. Velicanu,[141] R. Wolf,[141] B. Wyslouch,[141] M. Yang,[141] Y. Yilmaz,[141] A. S. Yoon,[141] M. Zanetti,[141] V. Zhukova,[141] B. Dahmes,[142] A. De Benedetti,[142] A. Gude,[142] J. Haupt,[142] S. C. Kao,[142] K. Klapoetke,[142] Y. Kubota,[142] J. Mans,[142] N. Pastika,[142] R. Rusack,[142] M. Sasseville,[142] A. Singovsky,[142] N. Tambe,[142] J. Turkewitz,[142] J. G. Acosta,[143] L. M. Cremaldi,[143] R. Kroeger,[143] S. Oliveros,[143] L. Perera,[143] R. Rahmat,[143] D. A. Sanders,[143] D. Summers,[143] E. Avdeeva,[144] K. Bloom,[144] S. Bose,[144] D. R. Claes,[144] A. Dominguez,[144] M. Eads,[144] R. Gonzalez Suarez,[144] J. Keller,[144] I. Kravchenko,[144] J. Lazo-Flores,[144] S. Malik,[144] F. Meier,[144] G. R. Snow,[144] J. Dolen,[145] A. Godshalk,[145] I. Iashvili,[145] S. Jain,[145] A. Kharchilava,[145] A. Kumar,[145] S. Rappoccio,[145] Z. Wan,[145] G. Alverson,[146] E. Barberis,[146] D. Baumgartel,[146] M. Chasco,[146] J. Haley,[146] A. Massironi,[146] D. Nash,[146] T. Orimoto,[146] D. Trocino,[146] D. Wood,[146] J. Zhang,[146] A. Anastassov,[147] K. A. Hahn,[147] A. Kubik,[147] L. Lusito,[147] N. Mucia,[147] N. Odell,[147] B. Pollack,[147] A. Pozdnyakov,[147] M. Schmitt,[147] S. Stoynev,[147] K. Sung,[147] M. Velasco,[147] S. Won,[147] D. Berry,[148] A. Brinkerhoff,[148] K. M. Chan,[148] M. Hildreth,[148] C. Jessop,[148] D. J. Karmgard,[148] J. Kolb,[148] K. Lannon,[148] W. Luo,[148] S. Lynch,[148] N. Marinelli,[148] D. M. Morse,[148] T. Pearson,[148] M. Planer,[148] R. Ruchti,[148] J. Slaunwhite,[148] N. Valls,[148] M. Wayne,[148] M. Wolf,[148] L. Antonelli,[149] B. Bylsma,[149] L. S. Durkin,[149] C. Hill,[149] R. Hughes,[149] K. Kotov,[149] T. Y. Ling,[149] D. Puigh,[149] M. Rodenburg,[149] G. Smith,[149] C. Vuosalo,[149] B. L. Winer,[149] H. Wolfe,[149] E. Berry,[150] P. Elmer,[150] V. Halyo,[150] P. Hebda,[150] J. Hegeman,[150] A. Hunt,[150] P. Jindal,[150] S. A. Koay,[150] P. Lujan,[150]

D. Marlow,[150] T. Medvedeva,[150] M. Mooney,[150] J. Olsen,[150] P. Piroué,[150] X. Quan,[150] A. Raval,[150] H. Saka,[150] D. Stickland,[150] C. Tully,[150] J. S. Werner,[150] S. C. Zenz,[150] A. Zuranski,[150] E. Brownson,[151] A. Lopez,[151] H. Mendez,[151] J. E. Ramirez Vargas,[151] E. Alagoz,[152] D. Benedetti,[152] G. Bolla,[152] D. Bortoletto,[152] M. De Mattia,[152] A. Everett,[152] Z. Hu,[152] M. Jones,[152] K. Jung,[152] O. Koybasi,[152] M. Kress,[152] N. Leonardo,[152] D. Lopes Pegna,[152] V. Maroussov,[152] P. Merkel,[152] D. H. Miller,[152] N. Neumeister,[152] I. Shipsey,[152] D. Silvers,[152] A. Svyatkovskiy,[152] F. Wang,[152] W. Xie,[152] L. Xu,[152] H. D. Yoo,[152] J. Zablocki,[152] Y. Zheng,[152] N. Parashar,[153] A. Adair,[154] B. Akgun,[154] K. M. Ecklund,[154] F. J. M. Geurts,[154] W. Li,[154] B. Michlin,[154] B. P. Padley,[154] R. Redjimi,[154] J. Roberts,[154] J. Zabel,[154] B. Betchart,[155] A. Bodek,[155] R. Covarelli,[155] P. de Barbaro,[155] R. Demina,[155] Y. Eshaq,[155] T. Ferbel,[155] A. Garcia-Bellido,[155] P. Goldenzweig,[155] J. Han,[155] A. Harel,[155] D. C. Miner,[155] G. Petrillo,[155] D. Vishnevskiy,[155] M. Zielinski,[155] A. Bhatti,[156] R. Ciesielski,[156] L. Demortier,[156] K. Goulianos,[156] G. Lungu,[156] S. Malik,[156] C. Mesropian,[156] S. Arora,[157] A. Barker,[157] J. P. Chou,[157] C. Contreras-Campana,[157] E. Contreras-Campana,[157] D. Duggan,[157] D. Ferencek,[157] Y. Gershtein,[157] R. Gray,[157] E. Halkiadakis,[157] D. Hidas,[157] A. Lath,[157] S. Panwalkar,[157] M. Park,[157] R. Patel,[157] V. Rekovic,[157] J. Robles,[157] S. Salur,[157] S. Schnetzer,[157] C. Seitz,[157] S. Somalwar,[157] R. Stone,[157] S. Thomas,[157] P. Thomassen,[157] M. Walker,[157] G. Cerizza,[158] M. Hollingsworth,[158] K. Rose,[158] S. Spanier,[158] Z. C. Yang,[158] A. York,[158] O. Bouhali,[159,jjj] R. Eusebi,[159] W. Flanagan,[159] J. Gilmore,[159] T. Kamon,[159,kkk] V. Khotilovich,[159] R. Montalvo,[159] I. Osipenkov,[159] Y. Pakhotin,[159] A. Perloff,[159] J. Roe,[159] A. Safonov,[159] T. Sakuma,[159] I. Suarez,[159] A. Tatarinov,[159] D. Toback,[159] N. Akchurin,[160] C. Cowden,[160] J. Damgov,[160] C. Dragoiu,[160] P. R. Dudero,[160] K. Kovitanggoon,[160] S. W. Lee,[160] T. Libeiro,[160] I. Volobouev,[160] E. Appelt,[161] A. G. Delannoy,[161] S. Greene,[161] A. Gurrola,[161] W. Johns,[161] C. Maguire,[161] Y. Mao,[161] A. Melo,[161] M. Sharma,[161] P. Sheldon,[161] B. Snook,[161] S. Tuo,[161] J. Velkovska,[161] M. W. Arenton,[162] S. Boutle,[162] B. Cox,[162] B. Francis,[162] J. Goodell,[162] R. Hirosky,[162] A. Ledovskoy,[162] C. Lin,[162] C. Neu,[162] J. Wood,[162] S. Gollapinni,[163] R. Harr,[163] P. E. Karchin,[163] C. Kottachchi Kankanamge Don,[163] P. Lamichhane,[163] A. Sakharov,[163] D. A. Belknap,[164] L. Borrello,[164] D. Carlsmith,[164] M. Cepeda,[164] S. Dasu,[164] S. Duric,[164] E. Friis,[164] M. Grothe,[164] R. Hall-Wilton,[164] M. Herndon,[164] A. Hervé,[164] P. Klabbers,[164] J. Klukas,[164] A. Lanaro,[164] R. Loveless,[164] A. Mohapatra,[164] I. Ojalvo,[164] T. Perry,[164] G. A. Pierro,[164] G. Polese,[164] I. Ross,[164] T. Sarangi,[164] A. Savin,[164] W. H. Smith,[164] and J. Swanson[164]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik der OeAW, Wien, Austria*
[3]*National Centre for Particle and High Energy Physics, Minsk, Belarus*
[4]*Universiteit Antwerpen, Antwerpen, Belgium*
[5]*Vrije Universiteit Brussel, Brussel, Belgium*
[6]*Université Libre de Bruxelles, Bruxelles, Belgium*
[7]*Ghent University, Ghent, Belgium*
[8]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[9]*Université de Mons, Mons, Belgium*
[10]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[11]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[12a]*Universidade Estadual Paulista, São Paulo, Brazil*
[12b]*Universidade Federal do ABC, São Paulo, Brazil*
[13]*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*
[14]*University of Sofia, Sofia, Bulgaria*
[15]*Institute of High Energy Physics, Beijing, China*
[16]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[17]*Universidad de Los Andes, Bogota, Colombia*
[18]*Technical University of Split, Split, Croatia*
[19]*University of Split, Split, Croatia*
[20]*Institute Rudjer Boskovic, Zagreb, Croatia*
[21]*University of Cyprus, Nicosia, Cyprus*
[22]*Charles University, Prague, Czech Republic*
[23]*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
[24]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*

[25]*Department of Physics, University of Helsinki, Helsinki, Finland*
[26]*Helsinki Institute of Physics, Helsinki, Finland*
[27]*Lappeenranta University of Technology, Lappeenranta, Finland*
[28]*DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France*
[29]*Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France*
[30]*Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France*
[31]*Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*
[32]*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*
[33]*Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia*
[34]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[35]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[36]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[37]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[38]*University of Hamburg, Hamburg, Germany*
[39]*Institut für Experimentelle Kernphysik, Karlsruhe, Germany*
[40]*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
[41]*University of Athens, Athens, Greece*
[42]*University of Ioánnina, Ioánnina, Greece*
[43]*KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary*
[44]*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
[45]*University of Debrecen, Debrecen, Hungary*
[46]*National Institute of Science Education and Research, Bhubaneswar, India*
[47]*Panjab University, Chandigarh, India*
[48]*University of Delhi, Delhi, India*
[49]*Saha Institute of Nuclear Physics, Kolkata, India*
[50]*Bhabha Atomic Research Centre, Mumbai, India*
[51]*Tata Institute of Fundamental Research-EHEP, Mumbai, India*
[52]*Tata Institute of Fundamental Research-HECR, Mumbai, India*
[53]*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
[54]*University College Dublin, Dublin, Ireland*
[55a]*INFN Sezione di Bari, Bari, Italy*
[55b]*Università di Bari, Bari, Italy*
[55c]*Politecnico di Bari, Bari, Italy*
[56a]*INFN Sezione di Bologna, Bologna, Italy*
[56b]*Università di Bologna, Bologna, Italy*
[57a]*INFN Sezione di Catania, Catania, Italy*
[57b]*Università di Catania, Catania, Italy*
[58a]*INFN Sezione di Firenze, Firenze, Italy*
[58b]*Università di Firenze, Firenze, Italy*
[59]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[60a]*INFN Sezione di Genova, Genova, Italy*
[60b]*Università di Genova, Genova, Italy*
[61a]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[61b]*Università di Milano-Bicocca, Milano, Italy*
[62a]*INFN Sezione di Napoli, Napoli, Italy*
[62b]*Università di Napoli 'Federico II', Napoli, Italy*
[62c]*Università della Basilicata (Potenza), Napoli, Italy*
[62d]*Università G. Marconi (Roma), Napoli, Italy*
[63a]*INFN Sezione di Padova, Padova, Italy*
[63b]*Università di Padova, Padova, Italy*
[63c]*Università di Trento (Trento), Padova, Italy*
[64a]*INFN Sezione di Pavia, Pavia, Italy*
[64b]*Università di Pavia, Pavia, Italy*
[65a]*INFN Sezione di Perugia, Perugia, Italy*
[65b]*Università di Perugia, Perugia, Italy*
[66a]*INFN Sezione di Pisa, Pisa, Italy*
[66b]*Università di Pisa, Pisa, Italy*
[66c]*Scuola Normale Superiore di Pisa, Pisa, Italy*
[67a]*INFN Sezione di Roma, Roma, Italy*
[67b]*Università di Roma, Roma, Italy*

[68a]*INFN Sezione di Torino, Torino, Italy*
[68b]*Università di Torino, Torino, Italy*
[68c]*Università del Piemonte Orientale (Novara), Torino, Italy*
[69a]*INFN Sezione di Trieste, Trieste, Italy*
[69b]*Università di Trieste, Trieste, Italy*
[70]*Kangwon National University, Chunchon, Korea*
[71]*Kyungpook National University, Daegu, Korea*
[72]*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
[73]*Korea University, Seoul, Korea*
[74]*University of Seoul, Seoul, Korea*
[75]*Sungkyunkwan University, Suwon, Korea*
[76]*Vilnius University, Vilnius, Lithuania*
[77]*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
[78]*Universidad Iberoamericana, Mexico City, Mexico*
[79]*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
[80]*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*
[81]*University of Auckland, Auckland, New Zealand*
[82]*University of Canterbury, Christchurch, New Zealand*
[83]*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
[84]*National Centre for Nuclear Research, Swierk, Poland*
[85]*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
[86]*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
[87]*Joint Institute for Nuclear Research, Dubna, Russia*
[88]*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
[89]*Institute for Nuclear Research, Moscow, Russia*
[90]*Institute for Theoretical and Experimental Physics, Moscow, Russia*
[91]*P. N. Lebedev Physical Institute, Moscow, Russia*
[92]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
[93]*State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*
[94]*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
[95]*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
[96]*Universidad Autónoma de Madrid, Madrid, Spain*
[97]*Universidad de Oviedo, Oviedo, Spain*
[98]*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
[99]*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[100]*Paul Scherrer Institut, Villigen, Switzerland*
[101]*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*
[102]*Universität Zürich, Zurich, Switzerland*
[103]*National Central University, Chung-Li, Taiwan*
[104]*National Taiwan University (NTU), Taipei, Taiwan*
[105]*Chulalongkorn University, Bangkok, Thailand*
[106]*Cukurova University, Adana, Turkey*
[107]*Middle East Technical University, Physics Department, Ankara, Turkey*
[108]*Bogazici University, Istanbul, Turkey*
[109]*Istanbul Technical University, Istanbul, Turkey*
[110]*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
[111]*University of Bristol, Bristol, United Kingdom*
[112]*Rutherford Appleton Laboratory, Didcot, United Kingdom*
[113]*Imperial College, London, United Kingdom*
[114]*Brunel University, Uxbridge, United Kingdom*
[115]*Baylor University, Waco, Texas, USA*
[116]*The University of Alabama, Tuscaloosa, Alabama, USA*
[117]*Boston University, Boston, Massachusetts, USA*
[118]*Brown University, Providence, Rhode Island, USA*
[119]*University of California, Davis, Davis, California, USA*
[120]*University of California, Los Angeles, Los Angeles, California, USA*
[121]*University of California, Riverside, Riverside, California, USA*
[122]*University of California, San Diego, La Jolla, California, USA*
[123]*University of California, Santa Barbara, Santa Barbara, California, USA*
[124]*California Institute of Technology, Pasadena, California, USA*
[125]*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*

[126]University of Colorado at Boulder, Boulder, Colorado, USA
[127]Cornell University, Ithaca, New York, USA
[128]Fairfield University, Fairfield, Connecticut, USA
[129]Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[130]University of Florida, Gainesville, Florida, USA
[131]Florida International University, Miami, Florida, USA
[132]Florida State University, Tallahassee, Florida, USA
[133]Florida Institute of Technology, Melbourne, Florida, USA
[134]University of Illinois at Chicago (UIC), Chicago, Illinois, USA
[135]The University of Iowa, Iowa City, Iowa, USA
[136]Johns Hopkins University, Baltimore, Maryland, USA
[137]The University of Kansas, Lawrence, Kansas, USA
[138]Kansas State University, Manhattan, Kansas, USA
[139]Lawrence Livermore National Laboratory, Livermore, California, USA
[140]University of Maryland, College Park, Maryland, USA
[141]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[142]University of Minnesota, Minneapolis, Minnesota, USA
[143]University of Mississippi, Oxford, Mississippi, USA
[144]University of Nebraska-Lincoln, Lincoln, Nebraska, USA
[145]State University of New York at Buffalo, Buffalo, New York, USA
[146]Northeastern University, Boston, Massachusetts, USA
[147]Northwestern University, Evanston, Illinois, USA
[148]University of Notre Dame, Notre Dame, Indiana, USA
[149]The Ohio State University, Columbus, Ohio, USA
[150]Princeton University, Princeton, New Jersey, USA
[151]University of Puerto Rico, Mayaguez, Puerto Rico
[152]Purdue University, West Lafayette, Indiana, USA
[153]Purdue University Calumet, Hammond, Indiana, USA
[154]Rice University, Houston, Texas, USA
[155]University of Rochester, Rochester, New York, USA
[156]The Rockefeller University, New York, New York, USA
[157]Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA
[158]University of Tennessee, Knoxville, Tennessee, USA
[159]Texas A&M University, College Station, Texas, USA
[160]Texas Tech University, Lubbock, Texas, USA
[161]Vanderbilt University, Nashville, Tennessee, USA
[162]University of Virginia, Charlottesville, Virginia, USA
[163]Wayne State University, Detroit, Michigan, USA
[164]University of Wisconsin, Madison, Wisconsin, USA

[a]Deceased.
[b]Also at Vienna University of Technology, Vienna, Austria.
[c]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[d]Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France.
[e]Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.
[f]Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
[g]Also at Universidade Estadual de Campinas, Campinas, Brazil.
[h]Also at California Institute of Technology, Pasadena, CA, USA.
[i]Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France.
[j]Also at Zewail City of Science and Technology, Zewail, Egypt.
[k]Also at Suez Canal University, Suez, Egypt.
[l]Also at Cairo University, Cairo, Egypt.
[m]Also at Fayoum University, El-Fayoum, Egypt.
[n]Also at British University in Egypt, Cairo, Egypt.
[o]Also at Ain Shams University, Cairo, Egypt.
[p]Also at National Centre for Nuclear Research, Swierk, Poland.
[q]Also at Université de Haute Alsace, Mulhouse, France.
[r]Also at Joint Institute for Nuclear Research, Dubna, Russia.

[s]Also at Brandenburg University of Technology, Cottbus, Germany.
[t]Also at The University of Kansas, Lawrence, KS, USA.
[u]Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[v]Also at Eötvös Loránd University, Budapest, Hungary.
[w]Also at Tata Institute of Fundamental Research-EHEP, Mumbai, India.
[x]Also at Tata Institute of Fundamental Research-HECR, Mumbai, India.
[y]Also at King Abdulaziz University, Jeddah, Saudi Arabia.
[z]Also at University of Visva-Bharati, Santiniketan, India.
[aa]Also at University of Ruhuna, Matara, Sri Lanka.
[bb]Also at Isfahan University of Technology, Isfahan, Iran.
[cc]Also at Sharif University of Technology, Tehran, Iran.
[dd]Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[ee]Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy.
[ff]Also at Università degli Studi di Siena, Siena, Italy.
[gg]Also at Purdue University, West Lafayette, IN, USA.
[hh]Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico.
[ii]Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[jj]Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.
[kk]Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
[ll]Also at University of Athens, Athens, Greece.
[mm]Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
[nn]Also at Paul Scherrer Institut, Villigen, Switzerland.
[oo]Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
[pp]Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
[qq]Also at Gaziosmanpasa University, Tokat, Turkey.
[rr]Also at Adiyaman University, Adiyaman, Turkey.
[ss]Also at Cag University, Mersin, Turkey.
[tt]Also at Mersin University, Mersin, Turkey.
[uu]Also at Izmir Institute of Technology, Izmir, Turkey.
[vv]Also at Ozyegin University, Istanbul, Turkey.
[ww]Also at Kafkas University, Kars, Turkey.
[xx]Also at Suleyman Demirel University, Isparta, Turkey.
[yy]Also at Ege University, Izmir, Turkey.
[zz]Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[aaa]Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey.
[bbb]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[ccc]Also at INFN Sezione di Perugia, Università di Perugia, Perugia, Italy.
[ddd]Also at Utah Valley University, Orem, UT, USA.
[eee]Also at Institute for Nuclear Research, Moscow, Russia.
[fff]Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[ggg]Also at Argonne National Laboratory, Argonne, IL, USA.
[hhh]Also at Erzincan University, Erzincan, Turkey.
[iii]Also at Yildiz Technical University, Istanbul, Turkey.
[jjj]Also at Texas A&M University at Qatar, Doha, Qatar.
[kkk]Also at Kyungpook National University, Daegu, Korea.